Semantic Conformance Testing Methodology and intial Results for Fingeprint Minutia Encoding

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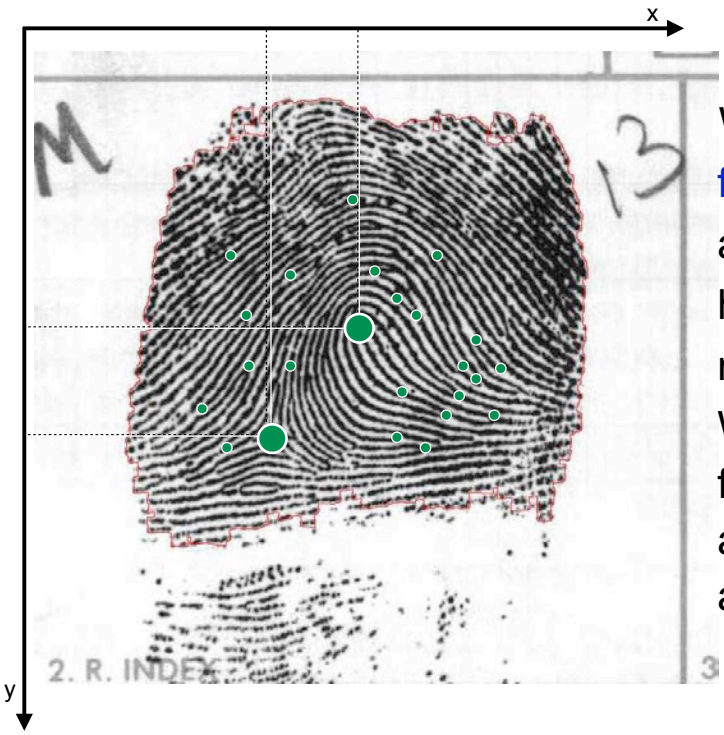
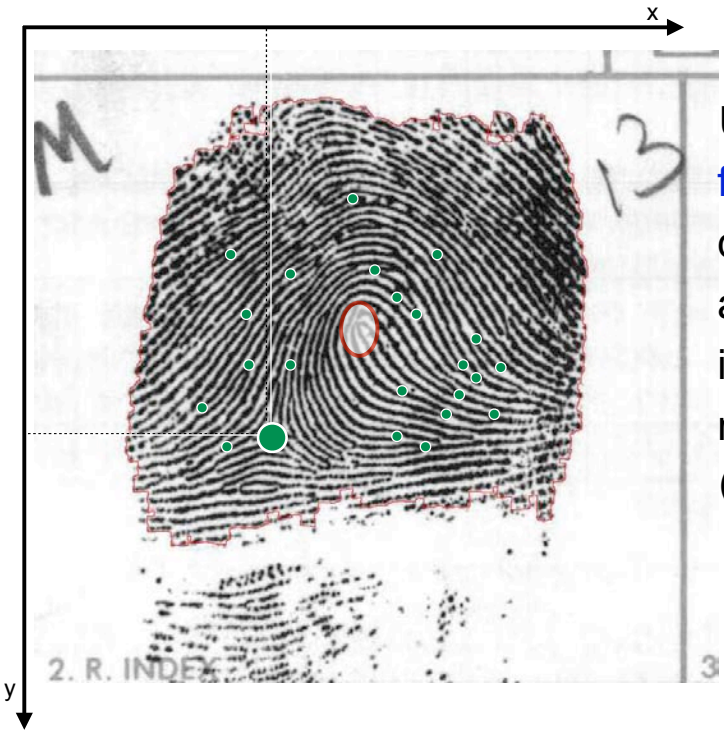
Properties of Finger Minutiae Detectors

Encoding the Minutia Format



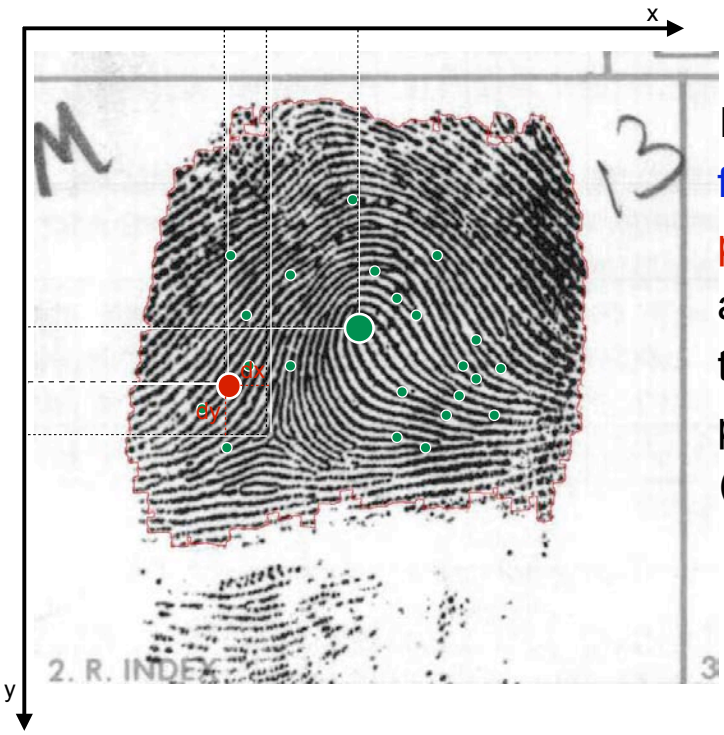
When a ISO 19794-2 compliant feature extractor processes a biometric fingerprint image he generates a minutiae template.
We will find the location for the core and for the delta and for many other minutiae.

Deficiencies of the Minutia Encoder



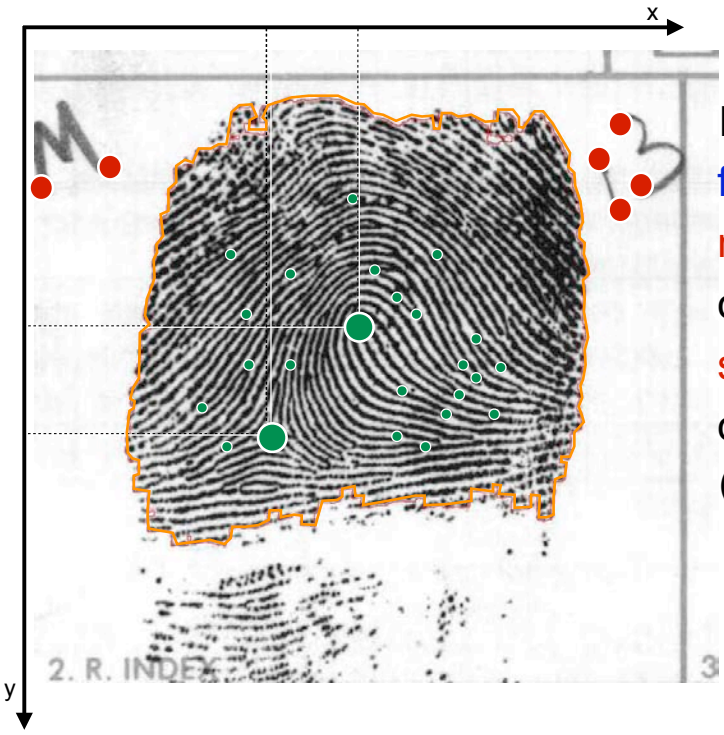
Unfortunately sometimes a feature extractor does not detect a landmark and thus relevant information is missing in the minutiae template. (sandstorm problem)

Deficiencies of the Minutia Encoder



In other cases a feature extractor fails to properly detect a landmark and thus encodes the feature at a dis-located position in the template. (fata morgana problem)

Deficiencies of the Minutia Encoder



Furthermore some feature extractor does not concentrate to the region of interest and thus detect spurious minutiae out of area or at the border of the imprint (globalisation problem)

Conformance Testing Methodology of
Finger Minutiae Detectors

Conformance Testing

Conformance testing is defined in a dedicated standard

- ISO/IEC IS 29109-1 Information technology — Conformance testing methodology for biometric data interchange formats defined in ISO/IEC 19794 — Part 1: Generalized conformance testing methodology
- ISO/IEC FDIS 29109-2 Information technology — Conformance testing methodology for biometric data interchange formats defined in ISO/IEC 19794 - Part 2: Finger minutiae data
- ISO/IEC 29109-1 formulates the relevant test type „A“:
  - attesting that a unit is generating conformant biometric data interchange records.
  - in the case of fingerprint data this tests will verify that a unit (e.g. a minutia extraction algorithm) can create finger minutiae data records (templates) from appropriate fingerprint image data.

Level of Conformance Testing

There are various level of conformance tests:

- Level 1 Basic Data Field Testing:
  - all data fields exist properly (e.g.in the correct encoding.)
- Level 2 Internal Consistency Testing:
  - all data fields are filled with meaningful values and the fields are internally consistent.
- Level 3 Semantic Testing:
  - a semantic test to verify that a generated biometric data interchange record is a faithful representation of the initial digital representation.

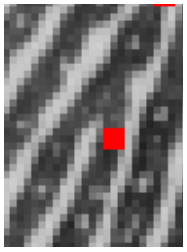
Semantic Conformance Testing

For fingerprint minutiae data

- template consists of automatically generated minutiae (*agm*)
  - *agm*'s are encoded by an implementation under test (IUT)
- semantic test to be covered by ISO/IEC 29109-2 AMD1
- semantic conformance is assessed by three rates:
  - 1.) Test for the sandstorm and the fata morgana problem:
    - Is the for every ground truth minutia (*gtm*) in the vicinity an automatically generated minutia (*agm*) in the template?
  - 2.) Test for the out-of-area problem (false minutia):
    - How many automatically generated minutiae (*agm*) are placed outside or at the border of a fingerprint area?
  - 3.) Test for spurious minutiae in the fingerprint area:
    - How many automatically generated minutiae (*agm*) do not have a mate in the gtm-set

Proposed Testing Methodology

- Sandstorm and fata morgana *gtm*-test:
  - The gt-minutiae assertion test yields a first conformance rate cr_{gtm}
    - indicating the proportion of elements in the set of gt-minutiae for which a corresponding minutia exists in the set of automatically generated minutiae,
    - such that values can be compared for each data field and differences can be measured.
    - the assertion requires the corresponding minutia to be in the vicinity.



bifurcation detected
dislocated as ridge ending

Proposed Testing Methodology

- Sandstorm and fata morgana *gtm*-test:
  - An exclusive gt-minutiae assertion test yields a first conformance rate cr_{gtm}

$$\mathrm{cr}_{gtm} = \frac{\sum_{i=1}^{ngtm} mcs_i}{ngtm}$$

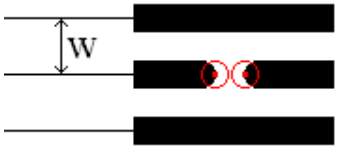
    - where $ngtm$ is the number of elements in the *gtm* set
    - and mcs_i is the minutia conformance score for the i-th gt-minutia that indicates the similarity between a *gtm* and the nearest minutia from the automatically generated minutiae set.
  - The mcs is non-zero, if the distance d between the minutiae positions is within the tolerance bounds tol_d.

Proposed Testing Methodology

- Minutia conformance score

$$\text{mcs} = \begin{cases} 0 & \text{if } d \geq tol_d \\ 1 - p & \text{otherwise} \end{cases}$$

$$\text{tol}_d = \frac{W}{4}$$



  - where p is a potential punishment $\text{p} = \text{p}_{\Delta\theta} + p_{\Delta t}$
    - dissimilarity in angle

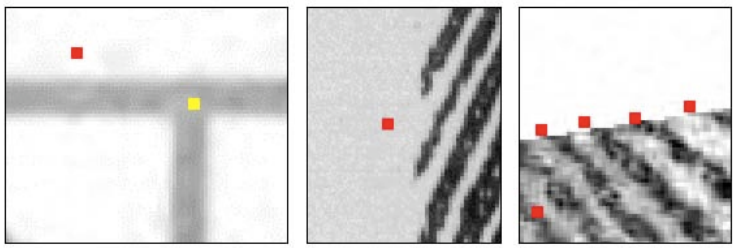
$$\text{p}_{\Delta\theta} = \frac{|\theta_{gtm} - \theta_{agm}| \cdot 0{,}5}{\pi}$$

    - dissimilarity in minutia type

$$\text{p}_{\Delta t} = \begin{cases} 0{,}25 & \text{if } t_{gtm} \neq t_{agm} \\ 0 & \text{otherwise} \end{cases}$$

Proposed Testing Methodology

- Out-of-area *agm*-test:
  - identify the number of outside false minutiae (false minutiae)
  - an inside-of-area *agm*-minutiae assertion test is yielding a second conformance rate cr_{agm} that is indicating the proportion of elements in the set of *agm* that are inside or at the borderline of the fingerprint area.



Proposed Testing Methodology

- Inside-of-area *agm*-test assertion:
  - second conformance rate cr_{agm}

$$\mathrm{cr}_{agm} = \frac{\sum_{i=1}^{nagm} mps_i}{nagm}$$

  - where $nagm$ is the number of elements in the *agm* set and mps_i is the minutia position score for the i-th ag-minutia that indicates the homogenious distribution of ag-minutia with respect to the fingerprint area.
  - metric will reflect a "punishment" for those *agm* that are on the borderline or outside the fingerprint area according

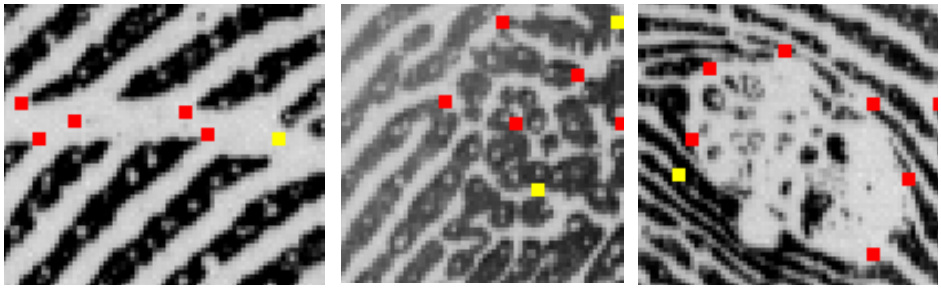
$$\mathrm{mps} = \begin{cases} 0 & \text{if } agm \text{ is outside the fingerprint area} \\ 0,5 & \text{if } agm \text{ is at the borderline} \\ 1 & \text{otherwise} \end{cases}$$

Proposed Testing Methodology

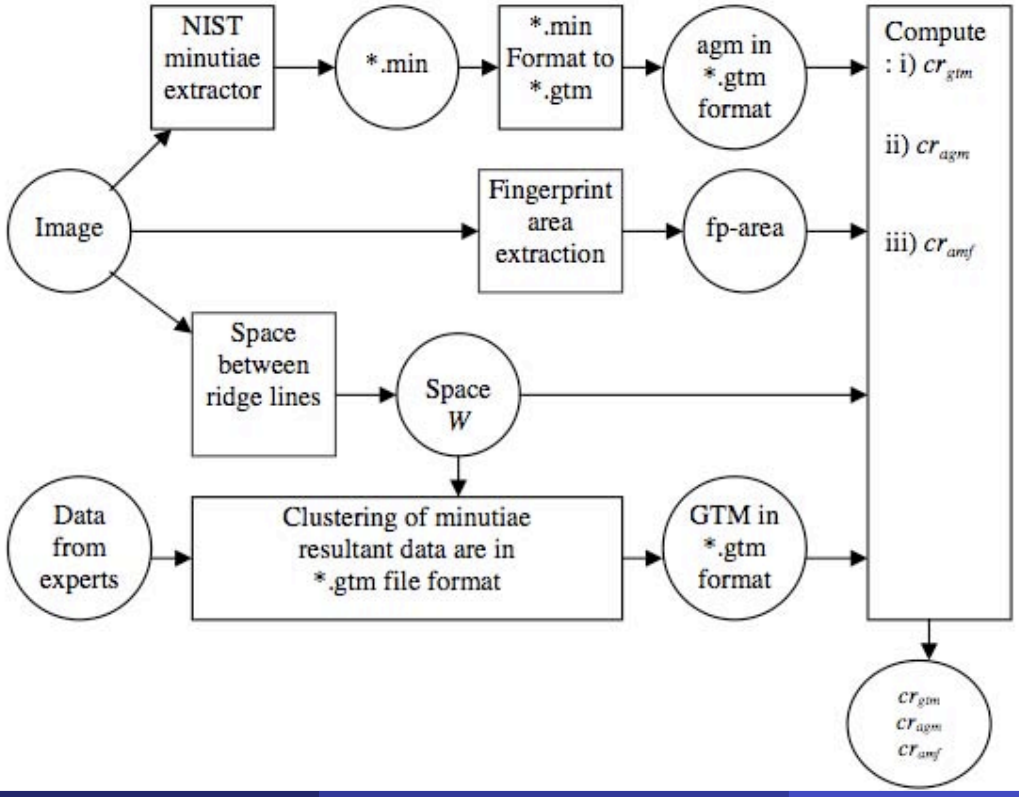
- Spurious *agm*-test:
  - The set of agm minutiae may contain spurious minutiae that are located in the fingerprint area
    - scars, bent skin, skin disease, dirt, etc.
  - third conformance rate cr_{amf}

$$\mathrm{cr}_{amf} = 1 - \frac{niagm}{nagm}$$

    - where $niagm$ is the number of focused *agm* inside the fingerprint area, which does not correspond to any *gtm*.



Testing Methodology Process Flow



Composing
Ground Truth Fingerprint Minutiae
Database

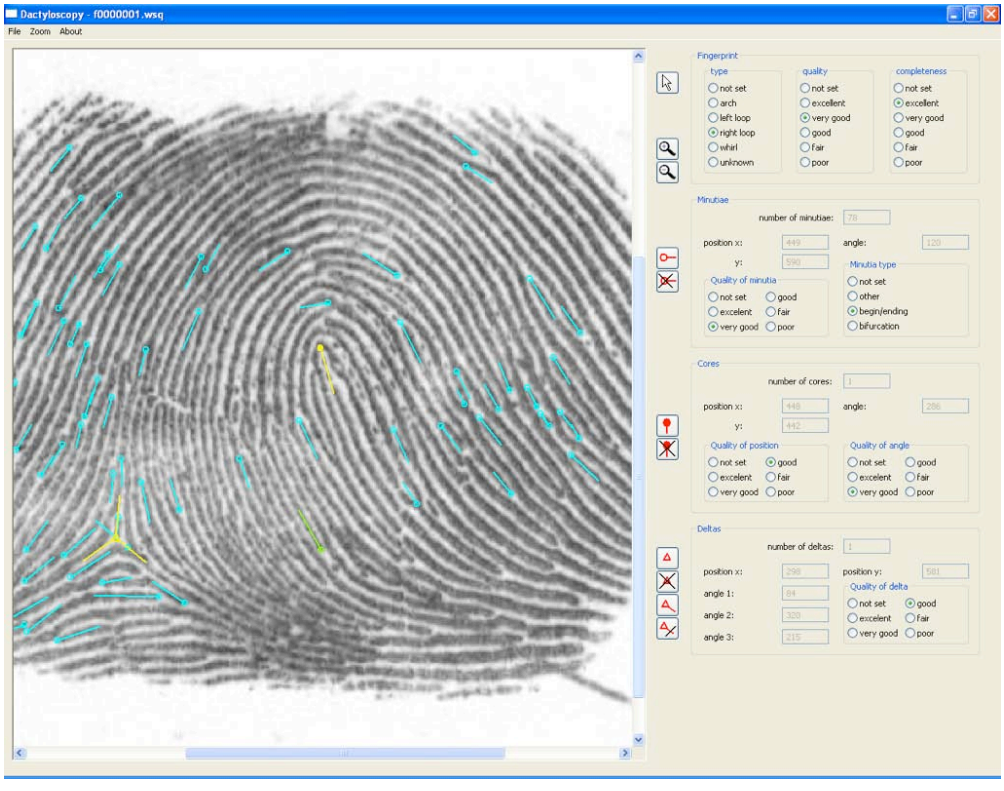
Semantic Conformance Testing

Challenge for implementing Semantic Testing:

- What is the „real minutia coordinate“?
- need for ground truth database (*gtd*) with minutiae data
  - need for public available fingerprint image data that is not restricted by privacy regulations
    - NIST special databases:
      SD14 rolled data and mostly ink with few live scanned images
      SD29 flat data /plain impression but all ink
  - need for dactyloscopic experts that define the truth!
    - Germany: Federal Criminal Police Office (BKA)
    - Australia: CrimeTrac (Andrew Wall)
    - Czech Republic: Criminalistic institute Prague
    - further volunteers?

Graphical User Interface

Ground Truth Minutia - GUI



Composing a Ground Truth Database

Ground Truth Minutia - data records

Data fields in *italics* are defined in correspondance to ISO 19794-2:2005

Data field	Description
Pattern type	1st Level classification according to the following Classification Codes: A = Arch; L = Left Loop; R = Right Loop; W = Whirl; U = Unknown.
Sample quality level	The level of difficulty to analyze the fingerprint is assessed as sample quality level according NFIQ[2] ranging from 1 "excellent", 2 "very good", 3 "good", 4 "fair" down to 5 "poor".
Sample completeness level	The level of completeness of the finger pattern.
Minutia type	The type can be ridge ending, ridge bifurcation or other (undetermined).
Minutia Position	The coordinates of the minutia (horizontal X and vertical Y).
Minutia Angle	Absolute angle of the minutia.
Minutia Quality	The quality figure for both position and angle.
Number of Cores	The number of core points represented.
Core Position	The coordinates of the core.
Core Position Quality	The quality (accuracy) figure.
Core Angle	The angle of the core is recorded.
Core Angle Quality	The quality (accuracy) figure.
Number of Deltas	The number of delta points represented.
Delta Position	The coordinates of the delta.
Delta Angle	The three angle attributes of the delta.
Delta Quality	The quality figure for both position and angle.

Composing a Ground Truth Database

Database Segments

- GTD-1: NIST SD14/SD29 selection
  - progress at BKA operation
    - Team of 11 dactyloscopic experts working partime on the Ground Truth Database
    - Approx. 1500 fingerprint images with 3 opinions as of January 15, 2010
- GTD-2: Latent fingerprints from crime scenes
  - operation to be started in April 2010
  - based on ELFT-EFS latent data
- GTD-3: Live prints
  - preparation work

Benefit of
a Ground Truth Minutiae
Database

Benefit of a Ground Truth Database

Database can serve for many purposes

- providing the ground for development of a semantic conformance test methodology
- providing the ground for semantic conformance tests according ISO 29109-2 AMD1
- providing the ground for development and calibration of fingerprint image sample quality metrics
  - NFIQ2-development and training
- providing the ground for dactyloscopic training software

Technical Challenges

Technical Challenges

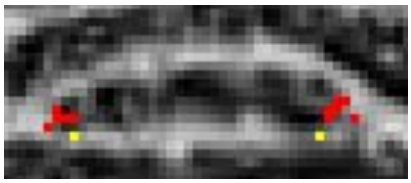
Strong impact on conformance rate by two factors

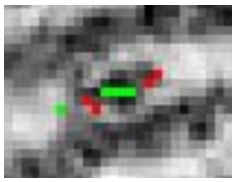
- minutiae clustering method
- fingerprint area definition

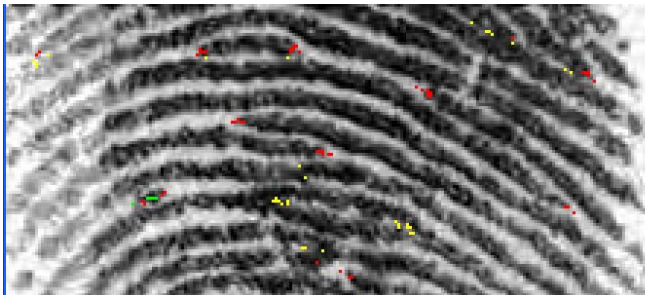
Technical Challenges

Clustering Minutiae Data

- Fusion of expert markup is a non-trivial taks
  - the number of clusters (minutiae) is unkown
  - the number of experts - contributing to one cluster- is also unkown.





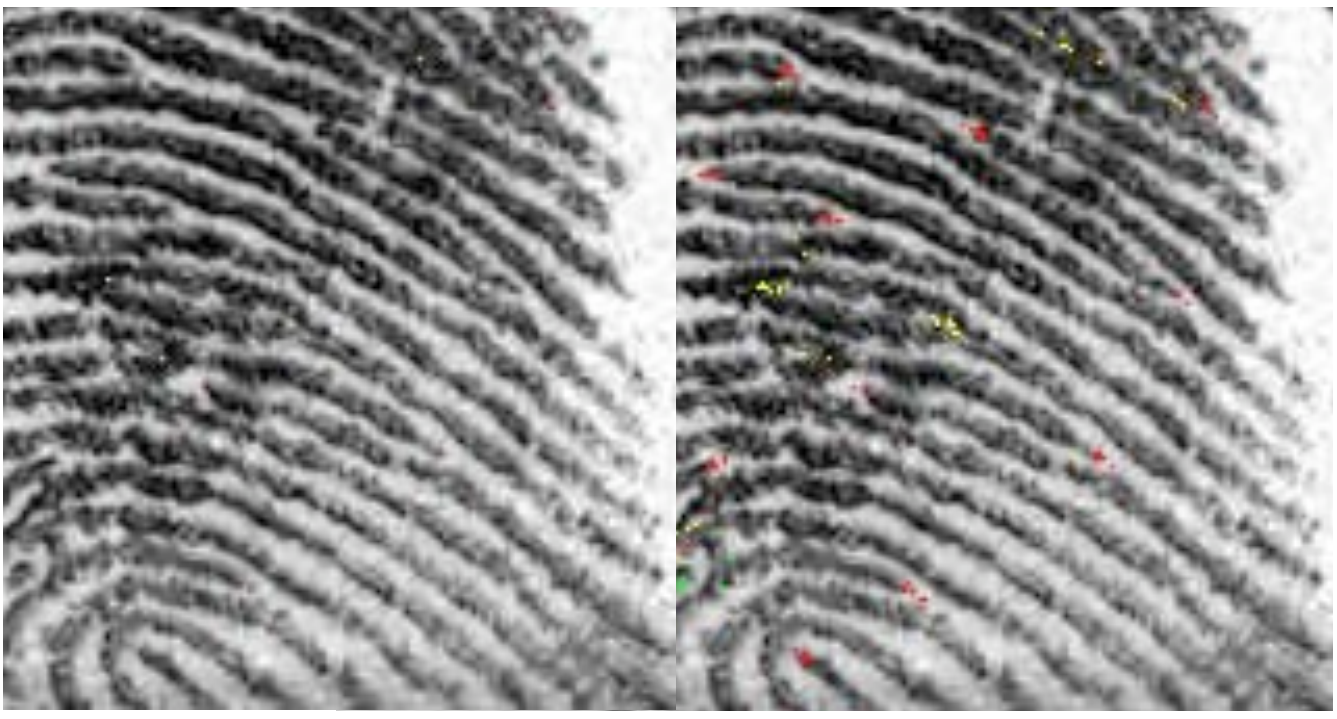


Clustering Minutiae Data

Automated Generated Minutia vs.Ground Truth Minutia

AGM - NIST mindtct

GTM



Clustering Minutiae Data

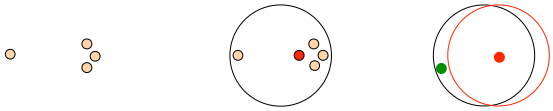
Identify cluster members

- Minutiae pairs, where:
  - Each minutiae has been placed by different expert.
  - The distance between minutiae is less or equal than W/2 (minutiae inside a circle with radius W/4).
- Triplets from minutiae pairs, where:
  - Pairs have one same (joint) minutiae + prev. cond.
  - Until n-tuples (n is number of experts).

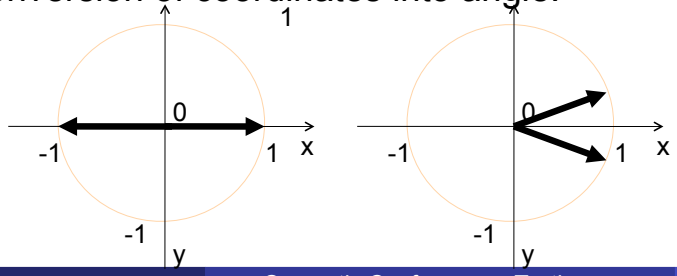
Clustering Minutiae Data

Identify consensus

- Average position $X_{GTM} = \frac{\sum_{i=1}^{ngtm} x_i}{ngtm}, \; Y_{GTM} = \frac{\sum_{i=1}^{ngtm} y_i}{ngtm}$



- Average type - UNKOWN, if less than 2/3 consensus
- Average angle
  - Conversion of angles into coordinates.
  - Computation of average coordinates.
    - Less than 1/3 of length means UNKNOWN.
  - Conversion of coordinates into angle.



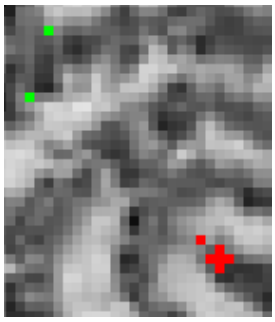
Clustering Minutiae Data

Identifying Reliable Minutiae Clusters

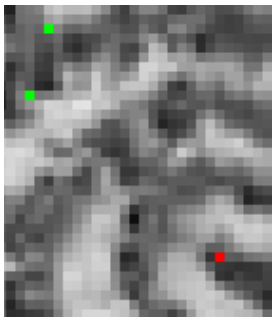
- How many experts identified this minutiae and how confident are they (quality of minutiae)?

$$q_{cl} = \frac{\sum_{i=1}^{ncl} q_i}{nexp}$$

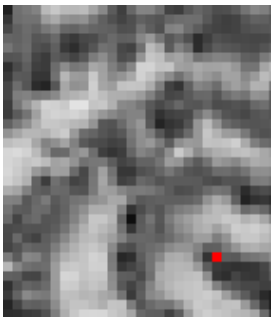
  - where q_i is the minutiauality of the i-th minutia in the cluster, ncl is the number of minutia in that cluster and $nexp$ is number of experts processing this image.



gtm from 11 experts



All cluster centers



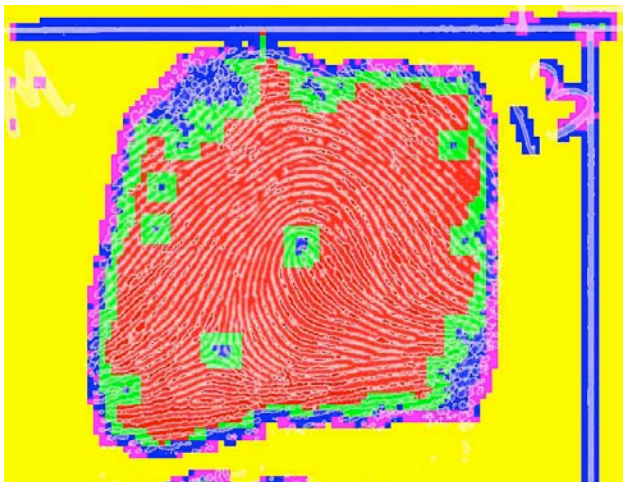
Most reliable cluster centers

Fingerprint Area Detection

Currently semi-automatic procedure

- A) segmentation according area quality of mindtct
- B) segmentation based on block-based gabor filter response
  - Shen et al. *Quality Measures of Fingerprint Images*
  - Alonso-Fernandez et al. *An Enhanced Gabor Filter-Based Segmentation Algorithm for Fingerprint Recognition Systems*

A



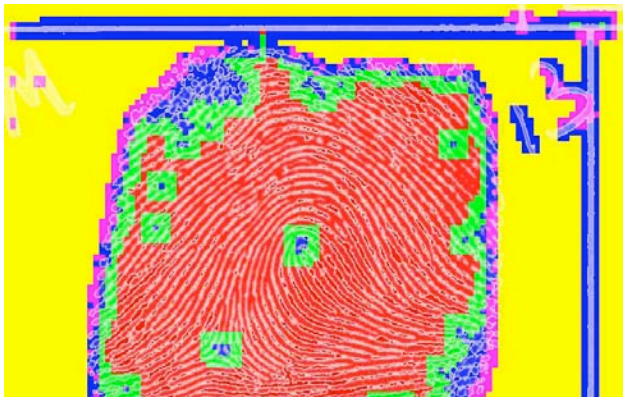
B

Fingerprint Area Detection

Currently semi-automatic procedure

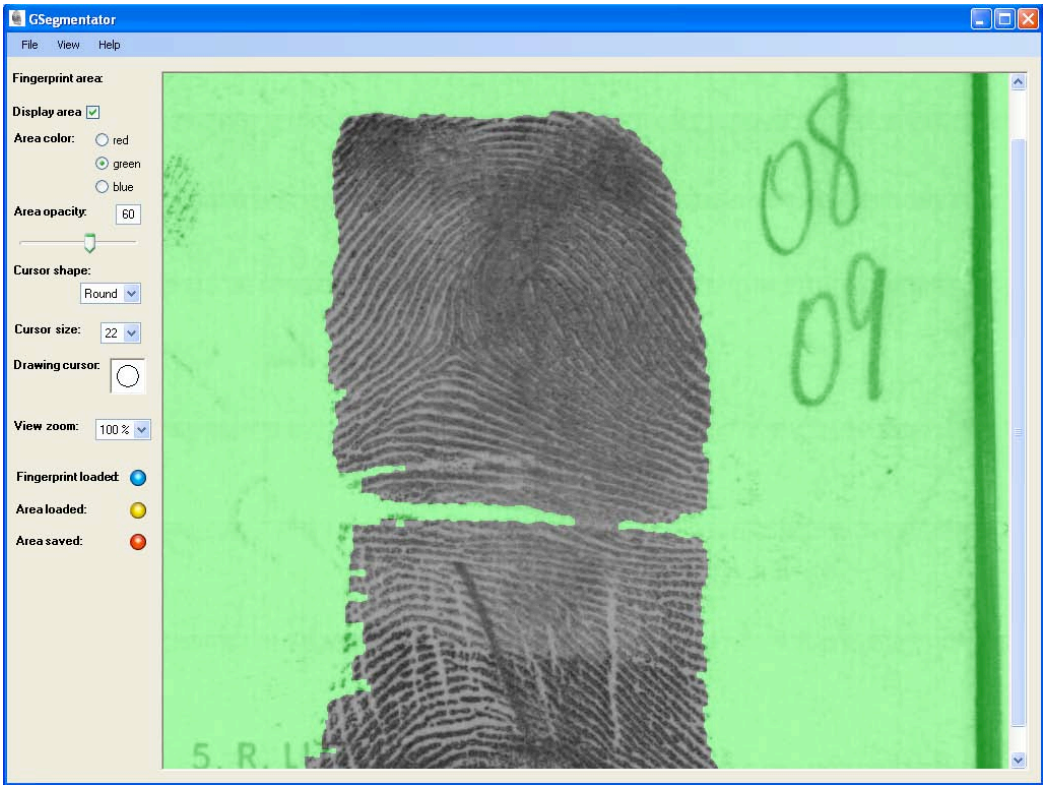
- segmentation according area quality of mindtct

Qual.	Color	Description
0/F:		low contrast OR no direction
1/D:		low flow OR high curve (with low contrast OR no direction neighbor) (or within NEIGHBOR_DELTA of edge)
2/C:		low flow OR high curve (or good quality with low contrast/no direction neighbor)
3/B:		good quality with low flow / high curve neighbor
4/A:		good quality (none of the above)



Fingerprint Area Detection

Manual inspection



Organisation Challenges

Challenges for the Ground Truth Database

Issues

- Synchronize work with progress of ISO 29109-2 AMD1
- Ground-Truth Database (gtd)
  - Identify more institutions
    from various dactyloscopic cultures
    contributing to the entire set
  - Keep the ground truth data confidential
    - NDAs with contributing institutions
    - The public fraction should contain approx. 30 percent of the total data and will be available in the public domain.
    - The sequester fraction will be provided under strong restriction to testing institution only
  - ISO/IEC JTC1 SC37 WG3 need to establish a procedure to autorize testing institution to receive a copy of the sequester database.

Initial Test Results

Test Results

Results BIOSIG 2009

- 17 images, max 11 experts each
- average $ngtm$: 59
- average agm: 100 (for NIST mindtct)

conformance rates	cr_{gtm}	cr_{agm}	cr_{amf}
average	0,353	0,885	0,662
std. deviation	0,179	0,066	0,178

Test Results

Results BioKey 2010

- Available ground truth data approx. 1000 images
- Dependency of the database
  - *cr = f (minutiae-extractor, db, ct-methodology)*
- Data set reduced (filtered) in cases
  - when less then 3 experts markups were available
  - where images showed archive artifacts
  - with two imprints in the image

- Data set not reduced
  - where images showed second phalanx
    - second phalanx is considered as part of the fingerprint area

Test Results

Results BioKeyS 2010

- 3 experts opinions each for 975 images (733 used)
  - SD14: 486 images / SD29: 247 images
- SD14 average *ngtm*: 76 (min 7 / max 174)
- SD14 average *agm*: 201 (min 87 / max 366) (NIST mindtct)

conformance rates	cr_{gtm}	cr_{agm}	cr_{amf}
average	0,464	0,857	0,645
std. deviation	0,092	0,063	0,123

- Generating this result was kindly supported by the German BSI under the BioKeyS-Pilot-DB project

Open Issues

Other deficiencies of extractors

- How to deal with Failure-to-eXtract
  - contribution with a cr=0

Respecting the minutia type

- if minutia type is „other“ we should not analyze the orientation

Conclusion

- Conformance testing essential step in system selection
- Semantic conformance testing requires ground truth data
- Further datyloscopic experts groups welcome
- Testing methodology under development
  - fusion of conformance rates
  - thresholds for the conformance rate
- Further data segments addressed soon

Further Information

on Semantic Conformance Testing

- On March 5, at 11:30 a session on fingerprint feature markup and testing will be held.
  - This workshop will discuss work in this area, interoperability, reference datasets, and the possibilities for semantic conformance testing.
- Publications:
  - C. Busch, D. Lodrova, E. Tabassi, W. Krodel: "Semantic Conformance Testing for Finger Minutiae Data", in Proceedings of the IEEE International Workshop on Security and Communication Networks (IWSCN), Trondheim, ISBN 978-82-997105-1-0, pages 17-23, (2009)
  - D. Lodrova, C. Busch, E. Tabassi, W. Krodel, M. Drahansky: „Semantic Conformance Testing Methodology for Finger Minutiae Data“, in Proceedings BIOSIG 2009, (2009)
- Website with information on the topic
  - http://www.igd.fraunhofer.de/~busch/gtd

Thank you for your attention
and many thanks
to the dactyoloscopic experts
contributing to the
ground truth database

Contact

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